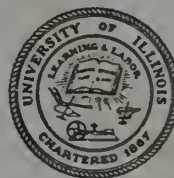Report No. 4

GENERAL PROBLEMS OF BROADBAND AMPLIFICATION IN THE MICROWAVE FREQUENCY RANGE

Quarterly Progress Report

CONTRACT NO. NONR 1834(08)
Project No. NR-373-162
OFFICE OF NAVAL RESEARCH

ELECTRON TUBE SECTION
ELECTRICAL ENGINEERING RESEARCH LABORATORY
ENGINEERING EXPERIMENT STATION
UNIVERSITY OF ILLINOIS
URBANA, ILLINOIS

GENERAL PROBLEMS OF BROADBAND
AMPLIFICATION IN THE
MICROWAVE FREQUENCY RANGE

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31 January 1957

Period Covered

1 October 1956

to

31 December 1956

Prepared by:

M. L. Babcock
K. R. Brunn

Approved by:

L. Goldstein
Professor

Electron Tube Section

Electrical Engineering Research Laboratory

Engineering Experiment Station

University of Illinois

Urbana, Illinois

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Attn. EL-41

Advisory Group on Electron Tubes
346 Broadway
New York 13, New York

Attn: Secretary, Working Group on
       Tube Techniques

M. Javid, Asst Professor
Illinois Institute of Technology
Technology Center
Chicago 16, Illinois

Electron Tube Development Department
Bell Telephone Laboratories
Murray Hill, New Jersey

Attn. Mr. J A Hornbeck

Winston M. Gottschalk
Raytheon Manufacturing Company
Research Division
Waltham 54, Massachusetts

Dr. H R Johnson
Room 2760, Bldg 12
Electron Tube Laboratories
Hughes Research Laboratories
Culver City, California

Eunice Lockhardt, Librarian
Electronics Research Laboratory
Stanford University
Stanford, California

Dr. T N Chin
R C A Laboratories
Lancaster, Pennsylvania

Dr. O T Purl
Electron Tube Laboratory
Research and Development Laboratory
Hughes Aircraft Company
Culver City, California

Mrs. Tereasa A Smith
Physics Laboratory
Sylvania Electric Products Inc
P O Box 6
Bayside, L I, N Y

Bell Telephone Laboratories, Inc
Murray Hill Laboratory
Murray Hill, New Jersey

Attn. MRD-2D-342

Dr. N T Grisamore
Electronics Research Projects
Building V
George Washington University
Washington 6, D.C.

Project Staff

Dr. H M Von Foerster   10

Dr. J T Tykociner
Electrical Engineering
    Research Laboratory
University of Illinois
Urbana, Illinois

CONTENTS

This is the fourth quarterly progress report issued under Contract Nonr 1834(08) and covers the period 1 October 1956 to 31 December 1956.

The research under this project deals with "General Problems of Broadband Amplification in the Microwave Frequency Range." The work is, in general, a continuation of research initiated under the terms of Contract N6-ori-071 Task XIX and later continued under Contract N6-ori-07156.

PERSONNEL

The following persons participated in contract activities during the report period:

Supervisor	Percent Time
L. Goldstein, Professor	5
Graduate Associates and Assistants:	
Murray L. Babcock, Research Assistant	100
Kenneth R. Brunn, Research Associate	100
D.F. Holshouser, Research Associate	25
Technicians:	
Robert N. Waggener, Senior Glass Blower	50
Hourly	
E. Maxon	Variable

1. INVESTIGATION OF THE TRIODE WITH A HOLLOW CATHODE -- M. L. Babcock

During this report period, two triodes, similar in construction and dimensions to those previously described, were completed and tested. The first tube's emission seemed to be satisfactory when operated initially as a diode, but when the triode connections were used, the total cathode emission was only about half the predicted value. No explanation of this effect is apparent, but it seems reasonable to assume that the shape of the field near the cathode aperture is different when the tube is operated under diode conditions and under triode conditions, with the result that different total cathode emission appears.

Tests on the first tube also indicated an unusually high percentage of the emission current being collected by the grid--over 70%--whereas the screening fraction for the grid used was only 0.25. Thus the grid collected two to three times as much current as predicted. The distortion of the field near the cathode aperture may account for this. Also, upon examination of the grid after removing it from the tube, it was found that the grid wires were displaced rather badly from their proper positions, several of them being in contact with each other and many having sagged such that they were no longer in the same plane as before. This could have resulted in an increased screening fraction for the grid.

The second tube assembled and tested contained a hollow cathode consisting of a 0.313 inch diameter sphere with an electron emission aperture 0.020 inch in diameter. The grid was a planar structure made of 0.0003 inch diameter tungsten wires placed 0.00120 inch on centers from each other. The plate was a planar disk made of steel and nickel-plated. The aperture-to-grid plane spacing was 0.032 inch and the grid-plane to plate spacing was

0.031 inch. Leakage resistance on this tube was greater than 10^{10} ohms between any two electrodes.

Figure 1 shows the transfer (mutual) characteristics for the second tube. As is seen from the curves, the amplification factor, μ , of the tube is not very constant, varying considerably with plate potential, e_b, and grid potential, e_c. For example, the μ for e_c = 0 volts and e_b = 80 volts is approximately 2000; the μ for e_c = 0 volts and e_b = 250 volts is approximately 1000. However, the transconductance, g_m, of the tube remains fairly constant over the range of grid potentials from -0.2 to +0.2 volts, being approximately 0.4 micromhos. The plate resistance, r_p, of the tube is about 10^9 ohms for grid potentials around zero volts.

Figure 2 is a graph of the logarithms of total cathode current versus the logarithm of equivalent voltage for plate voltage equal to zero potential. The curve also fits for very high μ . This figure is used to determine the constants in the equation for current for plane triodes as follows:

The current law for plane triodes is:

$$i_e = i_b + i_c = G(e_c + \frac{e_b}{\mu})^{\sigma} = G \, e_e^{\alpha}$$

in which i_e is the total cathode emission current in amperes

i_b is the total plate current in amperes

i_c is the total grid current in amperes

G is a constant known as the "perveance" of the tube

e_c is the grid potential in volts with respect to the cathode

e_b is the plate potential in volts with respect to the cathode

μ is the amplification factor of the tube

σ is a constant

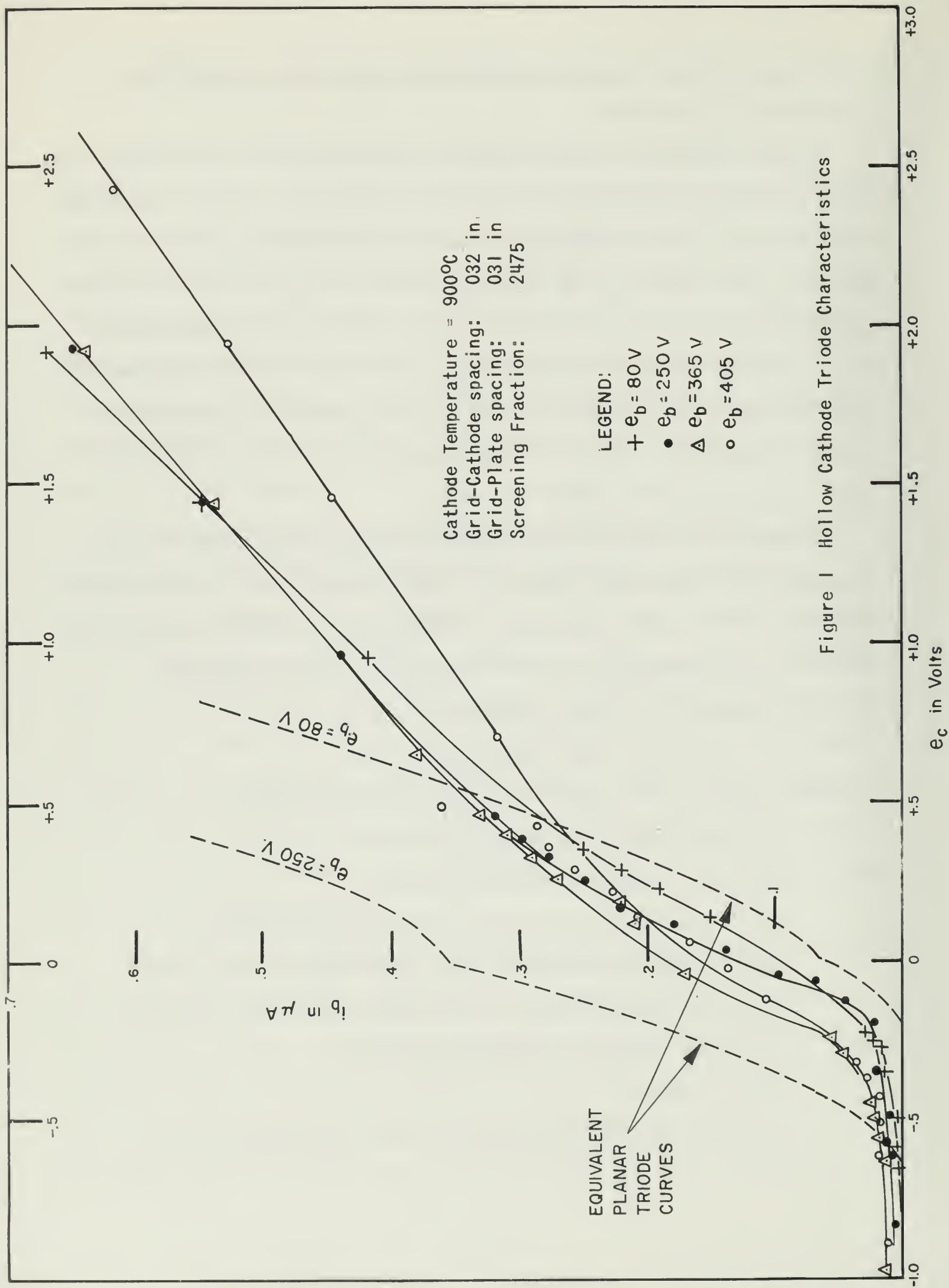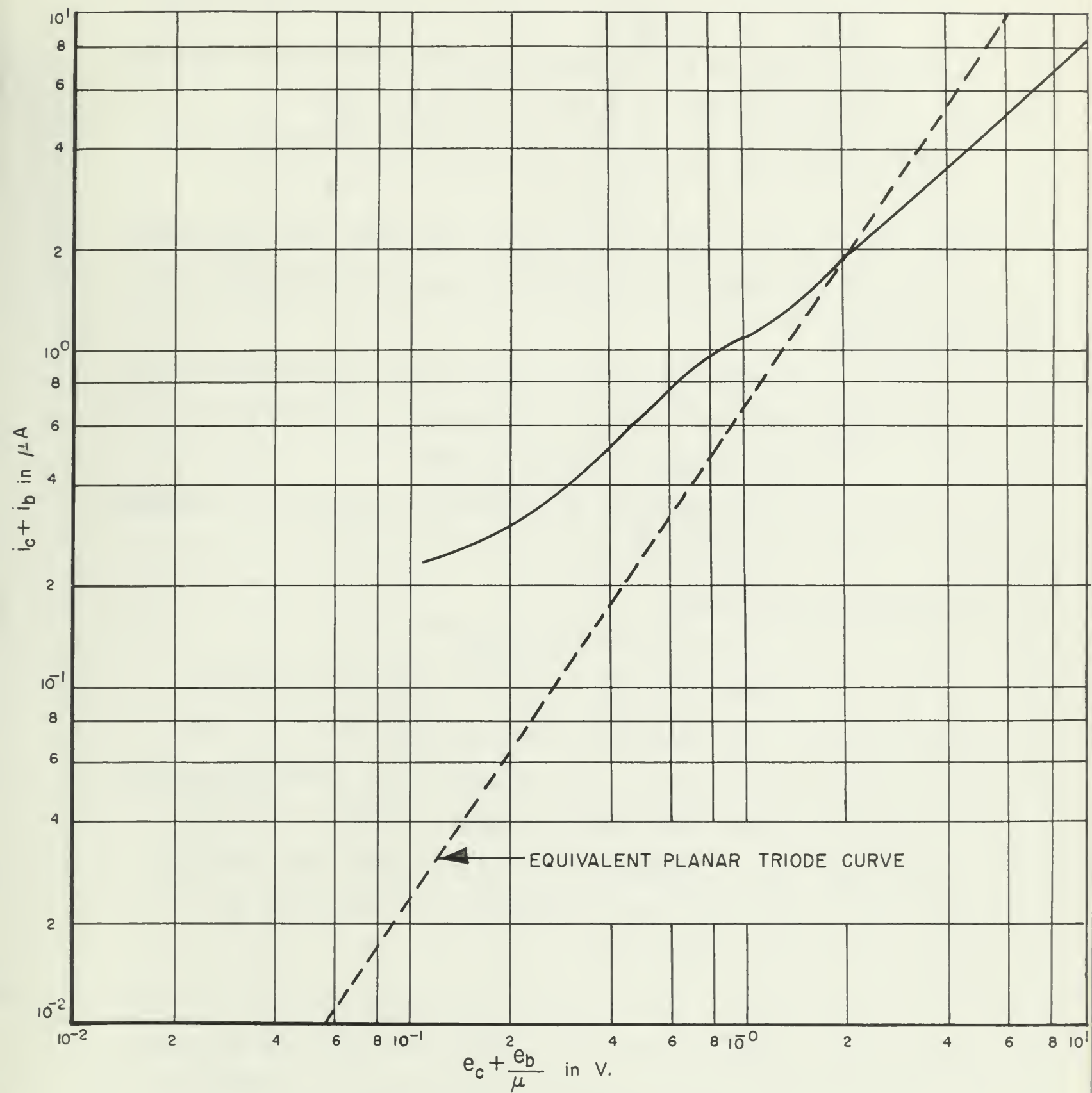e_e is the equivalent potential in volts with respect to the

Figure 1 Hollow Cathode Triode Characteristics

4

$e_b = 0$; Therefore Curve is Independent of μ.

Figure 2 Plot of Cathode Current versus Effective Voltage

5

cathode. ($e_e = e_c + \frac{e_b}{\mu}$).

Taking the logarithm of both sides of the above equation, the result is:

$$\log i_e = \log (i_b + i_c) = \log G + \alpha \log (e_c + \frac{e_b}{\mu}).$$

This equation has the slope-intercept form for a straight line:

$$y = mx + b,$$

and so a plot of $(i_b + i_c)$ versus $(e_c + \frac{e_b}{\mu})$ on logarithmic graph paper should

be a straight line if the tube is assumed to behave in a manner similar to a

planar triode.

Figure 2 is a reasonable straight line for values of equivalent voltage

above 1.5 volts. Thus the constants in the current law equation are:

α is the slope of the line = 0.90

G is the intercept of the line with $(e_c + \frac{e_b}{\mu} = 1)$ - coordinate

$= 1.05 \times 10^{-6}$.

The current law then becomes:

$$i_b + i_c = 1.05 \times 10^{-6} (e_c + \frac{e_b}{\mu})^{0.90}.$$

To better illustrate and compare the curves obtained with a planar

triode, the curves for a theoretical equivalent planar triode are shown as

dashed curves in Figures 1 and 2. The equivalent planar triode is one which

has identical structure, both geometrical shape and size, to the hollow

cathode triode, with the exception of the cathode itself. Here, the equi-

valent planar triode uses a planar cathode with the same area as the

aperture in the hollow cathode.

The dashed curves in Figure 1 are for plate potentials, e_b, of 80 volts

and 250 volts. Curves for other plate potentials would have the same shape,

but shifted in the negative or positive direction on the e_c - axis by an

amount $\frac{\Delta e_b}{\mu}$ from the one shown. From these curves it is seen that the

hollow cathode triode has greater current than the equivalent triode for plate potentials below about 100 volts. Also, the g_m of the hollow cathode triode is as good or better than the g_m of the equivalent triode and the r_p for plate potentials below 100 volts is better for the hollow cathode triode.

Several undesirable effects appeared in the second triode during its operation. For example, grid emission developed, but only in amount equal to 5% of the cathode emission. Incomplete activation apparently plagued the cathode, showing up as lack of repeatable data from one day to the next. Still other effects, common to all triodes tested so far, were the deformation of the grid due to the heat from the cathode and the coating of the grid wires with barium due to evaporation from the aperture. The effect of this barium build-up on the grid is to increase the screening fraction of the grid and thus cause the grid to intercept more electrons when it is positive than the calculated screening fraction would indicate. This actual screening fraction also increases with time, thus reducing the plate current as the tube ages.

Because of the latter effect, it is now believed that a new control electrode shape and placement are desirable for the final switching triode tube. Also, since the calculated constants of the tube using planar triode theory differ considerably from the experimental constants, it seems likely that planar theory is not applicable to the design of the tube. However, the comparison between the equivalent triode and the hollow cathode triode indicates that a triode having considerably different characteristics from the conventional triode can be developed.

One additional triode remains to be tested as a final source of some more conclusive information, and then a new approach to the design will be started. The new approach will be to influence the electric field shape at

the cathode aperture by means of control grids which do not intercept
electrons emitted from the aperture. Several means of doing this are now
being considered.

2. THE HIGH VOLTAGE HOLLOW CATHODE INVESTIGATION -- K.R. Brunn

The high voltage hollow cathode investigation has been completed and
a detailed technical report has been written and is currently being prepared
for publication. The title of this report, which is expected to be avail-
able for distribution in mid-March, is "An Investigation of the Hollow
Spherical Cathode: Part I. Emission Mechanisms of Hollow Spherical
Cathodes; Part II. Development of a High Level Pulser".